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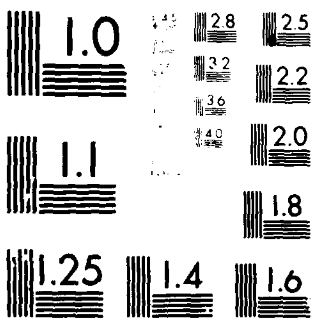

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Technical Report
MII Project M-247
February 1980

THE APPLICATION OF MEASURES OF SYNOPTIC SIMILARITY TO THE EVALUATION AND DEVELOPMENT OF ATMOSPHERIC PREDICTION MODELS: TASK 2

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NOTE:

This Report is a Supplement to A073092

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1. GENERAL INTRODUCTION

In February 1978, Meteorology International Incorporated (MII) submitted an unsolicited proposal to the Naval Environmental Prediction Research Facility (NEPRF) concerning the development of a comprehensive system for the evaluation of atmospheric models based on Measures Of Synoptic Similarity (MOSS). It was suggested that overall development of the MOSS system be carried out under a series of Tasks. The proposal specifically addressed Task 1 which was intended to establish a basic MOSS system, MOSS1, and to demonstrate that an overall measure of the degree of pattern similarity between two synoptic fields could indeed be obtained and utilized in the context of model development, verification and evaluation. If the MOSS1 system proved to be an effective tool, thus substantiating the underlying concepts, then further capabilities, refinements and flexibility could be added under subsequent Tasks. It was considered that this approach would prove more effective and efficient than implementing an initially more comprehensive system.

The Proposal was accepted and, under Contract Number N00228-78-C-3258, the MOSS1 system was designed, programmed and tested by application to sequences of FNOC PE forecasts and verifying analyses. The results provided a convincing demonstration of the effectiveness of the concepts underlying the MOSS1 capability and of the potential utility of a MOSS system.

The Final Report for Task 1 was submitted to NEPRF in January 1979 and has been reproduced and distributed by NEPRF under Report Number NAVENVPREDRSCHFAC CR79-01 dated March 1979.

MOSS1, although a valuable tool in its own right, is subject to a variety of constraints. In particular, for each range-of-scale component, MOSS1 provides a <u>single</u> measure representing the degree of pattern similarity between two northern hemisphere fields as a whole; MOSS1 has no developed capability for scoring forecasts in various regions of the hemisphere. Since naval operations generally are conducted in particular regions the ability to objectively examine specific regions of hemispheric forecast fields is desirable. This capability would allow an objective evaluation to be made of the ability of a forecast model to include regional factors and would make possible the consistent monitoring of regional biases in forecast accuracy.

In March 1979 MII submitted Proposal No. P-302B. The Proposal addressed Task 2 of the overall development of the MOSS system. Task 2 was intended, primarily, to extend the scoring capabilities of MOSS1 to provide an areal distribution of match coefficients over either hemisphere. MII Proposal No. P-302B was accepted and funded under Contract Number N00228-79-C-PP35 dated 10 September 1979; the work has been performed as MII Project Number M-247.

This Report, the Final Report for Task 2 of the overall development of the MOSS system, has been written as a Supplement to the Final Report for Task 1 referenced above. Familiarity with and access to that Report is assumed. The expanded MOSS system resulting from performance of Task 2 is known as MOSS2.[1]

[1] Section 7 of the Final Report for Task 1 contains a proposed System Description for MOSS2. It may be noted that only parts of the originally-proposed capabilities for MOSS2 have been implemented under Task 2 (described herein). Those features not encompassed by Task 2 may be added as a further stage of development.

2. TASK 2 OBJECTIVES

Extend the MOSS1 system to provide the MOSS2 system by incorporating the following additional features and capabilities:

a. A capability for producing MOSS scores for the southern hemisphere;

b. A capability for utilizing User-specified range-level values;

c. A capability for matching, in ranges-of-scale, either 1000-mb fields only or 500-mb fields only, and for matching fields which have been pattern-separated prior to input to the MOSS2 system;

d. A capability for producing an areal distribution of match coefficients for the SV, SL and SD ranges-of-scale at 500-mb, 1000-mb, and/or the 500-1000-mb thickness.

e. A capability for producing an areal distribution of match coefficients which are a User-weighted combination of the SV, SL and SD ranges-of-scale;

f. A capability for displaying the results of the MOSS2 system in tabulated formats.

3. THE MOSS2 SYSTEM

3.1 Introduction

MOSS1 was delivered to NEPRF in January 1979 as a program installed on the FNOC R&D computer. During 1979 NEPRF personnel placed the MOSS1 system on the FNOC operational system where it is now used by NEPRF in association with numerical models being developed by NEPRF. A number of changes to the MOSS1 system were made by NEPRF following the original development by MII. However these changes are essentially procedural, designed to facilitate the production of MOSS1 scores in an operational environment. The underlying concepts and basic capabilities of the MOSS1 system have not been modified.

Modifications to MOSS1 to provide MOSS2 are described below; only system changes are described. The associated source-code to effect these changes has been submitted as an update to the MOSS1 program as modified by NEPRF personnel, not to the program originally delivered by MII.

3.2 System Constraints

MOSS2 system constraints include:

a. The fields are, or are derived from, 1000-mb or 500-mb height fields, or 500-1000-mb thickness fields;

b. Scores are based on fields expressed in terms of their component ranges-of-scale;

c. The fields are on a hemispheric grid, polar stereographic projection, in the standard FNOC 63x63 format including IDENT.

3.3 The Southern Hemisphere Capability (Objective a.)

The MOSS bit-coding methodology, outlined in Section 3.3 of the MOSS1 Report, is designed for application to a hemispheric analysis or forecast field on a 63x63 polar stereographic grid. Clearly the bit-coding procedure is equally applicable to either hemisphere. The MOSS2 system has been provided with a capability for recognizing and selecting the appropriate fields to be compared and scored.

As stated in Section 3.3 of the MOSS1 Report, in order to effect greater discrimination in the coding of the planetary vortex (SV) range-of-scale field, the coding is applied to the anomaly of this field from a long-term (annual) mean field: $SV - \overline{SV}$. The MOSS1 system (applicable to Northern Hemisphere fields only) accesses stored values of $\overline{SV}$ at appropriate points in the program. Values of $\overline{SV}$ are available for the Northern Hemisphere but not for the Southern Hemisphere.

In seeking a solution to this problem, generating $\overline{SV}$ fields for the Southern Hemisphere was considered as was using the available Northern Hemisphere fields for both hemispheres. However study of the available $\overline{SV}$ fields showed that an acceptable and expedient solution is to approximate $\overline{SV}$ mean values as follows:

a. $\overline{SV}_{500} = 3 \times 10^4 \times \cos 2\varphi$ (units: cms.)

where φ is the latitude, north or south.

b. $\overline{SV}_{1000} = 0.$

c. $\overline{SV}_{5-10} = \overline{SV}_{500}.$

In the MOSS2 system $\overline{SV}$ values are approximated, for either hemisphere, by the above expressions for each run of the MOSS2 system.

3.4 Range-Level Specification (Objective b.)

The use of range-levels for each of the seventeen parameters used to define modular patterns is discussed in Section 3.3 of the MOSS1 Report; however, as an example, only the values of parameter A for an SD_{1000} field are given.

Table 1 shows, for each of the nine component fields, the numerical values of all range levels for the seventeen pattern-specifying parameters. These values are accessed by module BITCODE (see Section 3.5).

To provide greater flexibility MOSS2 provides three complete sets of range-levels. The first set, termed the "default set", will be accessed by module BITCODE (for both Northern and Southern Hemisphere fields) if the User does not require that one of the other two sets be used. The second set is intended to contain User-specified range-levels for the Northern Hemisphere; the third set is intended to contain User-specified range-levels for the Southern Hemisphere.[1]

[1] As delivered by MII, all three sets of range-levels for MOSS2 have been set to correspond to Table 1.

Table 1
Range levels for pattern-specifying parameters, A through Q, for each of the nine component fields.

Field: SV_{500} (all units in cms.)

A,B:	7930	5365	3149	1493	0	-1493	-3149	-5365	-7930
C:			9847	5193	0	-5193	-9847		
D,E:		12550	7910	3993	0	-3993	-7910	-12550	
F,G,H,I:			6358	3448	0	-3448	-6538		
J-Q:				3195	0	-3195			

Field: SV_{1000}

A,B:	7354	4975	2920	1384	0	-1384	-2920	-4975	-7354
C:			9860	5200	0	-5200	-9860		
D,E:		13875	8745	4415	0	-4415	-8745	-13875	
F,G,H,I:			6902	3640	0	-3640	-6902		
J-Q:				3531	0	-3531			

Field: SV_{5-10}

A,B:	7480	5060	2970	1408	0	-1408	-2970	-5060	-7480
C:			9779	5157	0	-5157	-9779		
D,E:		12670	7986	4031	0	-4031	-7986	-12670	
F,G,H,I:			7709	4066	0	-4066	-7709		
J-Q:				3226	0	-3226			

Table 1 (Continued)

Field: SL_{500}

A,B:	12407	8393	4926	2335	0	-2335	-4926	-8393	-12407
C:			13810	7283	0	-7283	-13810		
D,E:		15650	9864	4980	0	-4980	-9864	-15650	
F,G,H,I:			9544	5033	0	-5033	-9544		
J-Q:				4783	0	-4783			

Field: SL_{1000}

A,B:	5153	3486	2046	970	0	-970	-2046	-3486	-5153
C:			5828	3073	0	-3073	-5828		
D,E:		7178	4524	2284	0	-2284	-4524	-7178	
F,G,H,I:			4465	2354	0	-2354	-4465		
J-Q:				2243	0	-2243			

Field: SL_{5-10}

A,B:	10977	7426	4358	2066	0	-2066	-4358	-7426	-10977
C:			11790	6217	0	-6217	-11790		
D,E:		13972	8807	4446	0	-4446	-8807	-13972	
F,G,H,I:			8225	4338	0	-4338	-8225		
J-Q:				4260	0	-4260			

Table 1 (Continued)

Field: SD_{500}

A,B:	7480	5060	2970	1408	0	-1408	-2970	-5060	-7480
C:			8018	4228	0	-4228	-8018		
D,E:		10058	6340	3200	0	-3200	-6340	-10058	
F,G,H,I:			5704	3008	0	-3008	-5704		
J-Q:				2520	0	-2520			

Field: SD_{1000}

A,B:	4420	2990	1755	832	0	-832	-1755	-2990	-4420
C:			4851	2558	0	-2558	-4851		
D,E:		6115	3854	1946	0	-1946	-3854	-6115	
F,G,H,I:			3933	2074	0	-2074	-3933		
J-Q:				1680	0	-1680			

Field: SD_{5-10}

A,B:	6630	4485	2632	1248	0	-1248	-2632	-4485	-6630
C:			7142	3766	0	-3766	-7142		
D,E:		8781	5535	2794	0	-2794	-5535	-8781	
F,G,H,I:			5394	2844	0	-2844	-5394		
J-Q:				2352	0	-2352			

3.5 Selecting Fields to be Matched (Objective c.)

Prior to development of MOSS2, MOSS1 was modified by NEPRF so that when reading a field from the FNOC master file (MASFNWC) the scale-separated components (SV, SL, SD) of that field are requested first. If all three components are available, scale separation is not necessary and module SCLSEP is by-passed. If any component range-of-scale is not available then the "total field" (the D field) is requested and passed to module SCLSEP. Note that in the original version of MOSS1, the SV anomaly was determined as part of SCLSEP. Thus, for instances where SCLSEP is by-passed, MOSS1 was modified to make separate provision for computing the SV-anomaly field. These modifications to MOSS1 have been incorporated into MOSS2; however, the SV anomaly is now determined as described in Section 3.3 above.

The MOSS2 ability to match either 1000-mb fields only or 500-mb fields only is based on a User-specified 9-element matrix, WT. There is a one-to-one correspondence between matrix elements and the nine component fields which represent a synoptic situation, thus;

WT(1)	is associated with	SV_{500}
WT(2)		SV_{1000}
WT(3)		SV_{5-10}
WT(4)		SL_{500}
WT(5)		SL_{1000}
WT(6)		SL_{5-10}
WT(7)		SD_{500}
WT(8)		SD_{1000}
WT(9)		SD_{5-10}

If the User sets any elements of WT to zero he is specifying the associated component-fields as "not required" in the subsequent determination of MOSS2 scores. Thus to match pairs of 500-mb fields only (i.e., excluding matches for 1000-mb and 500-1000-mb field components), WT may be specified by the User as:

$$WT = 1, 0, 0, 1, 0, 0, 1, 0, 0 \quad .$$

From this specification MOSS2 recognizes that the corresponding-in-time 1000-mb fields are not required and does not access them.

Similarly if WT is specified as:

$$WT = 0, 1, 0, 0, 1, 0, 0, 1, 0$$

then the User is calling for a 1000-mb match only; the corresponding-in-time 500-mb fields will not be accessed.

The WT array thus provides MOSS2 with a capability for matching 1000-mb fields only or 500-mb fields only and hence satisfies the requirements of Objective c. However, as explained in the following Sections, WT provides greater flexibility in the selection of fields to be matched. Any elements of WT may be set to zero. Thus if

$$WT = 0, 0, 0, 1, 0, 0, 0, 0, 0$$

then the resulting MOSS2 score will be for a match of SL_{500} fields only. WT is also used to specify the required weighted combination of SV, SL and SD ranges-of-scale (Objective e.).

3.6 The Areal Distribution of Match Coefficients (Objective d.)

In the MOSS system, each synoptic situation is represented by a 588-word bit-string. An additional word contains the date-time group. Pertinent details of this 589-word record are given in the following table:

Table 2
The 589-word record for a synoptic situation.

FIELD/DTG	Number of words for representation	Number of bits for representation	Location of words in record
DTG	1	--	1
SV_{500}	16	960	2 → 17
SV_{1000}	16	960	18 → 33
SV_{5-10}	16	960	34 → 49
SL_{500}	36	2160	50 → 85
SL_{1000}	36	2160	86 → 121
SL_{5-10}	36	2160	122 → 157
SD_{500}	144	8640	158 → 301
SD_{1000}	144	8640	302 → 445
SD_{5-10}	144	8640	446 → 589

Now consider matching a forecast situation with the verifying analysis--e.g., $F_{\tau+n}:A_{\tau+n}$.[1] In the MOSS1 system, module MATCH compares the bit-string representations of the two situations. A count is made of the total number of bits that match within the two subsets

[1] See Section 5.1 of the MOSS1 Report for an explanation of this nomenclature.

of words allocated to a particular component-field. This number, divided by the total number of allocated bits (given in Table 2) and multiplied by 1000, provides the MOSS1 score for that component. The score is a single monotonic measure of the degree of similarity between the component pair where each component has been expressed in terms of the seventeen pattern-specifying parameters. Thus MOSS1 provides nine scores for each match of the type $F_{\tau+n} : A_{\tau+n}$. A number of examples of MOSS1 scores are given in the MOSS1 Report.

As discussed in Section 3.3 of the MOSS1 Report, a hemisphere is divided into 16 modules (a 4x4 array) on the SV range-of-scale, into 36 modules (a 6x6 array) on the SL range-of-scale, and into 144 modules (a 12x12)[1] array on the SD range-of-scale. In the 588-word bit-string shown in Table 2, a single 60-bit word is used to represent the values (in terms of range levels) of the seventeen pattern-specifying parameters for <u>each</u> module. (Note that the numbers of words given in column 2 of Table 2 correspond to the numbers of SV, SL and SD modules used for a hemisphere.)

The MOSS2 capability for providing an areal distribution of match coefficients (rather than the single hemispheric score provided by MOSS1) is based on scoring two component-fields module-by-module. Clearly the maximum possible score of matching bits for any module will be 60 irrespective of the range-of-scale being considered.

In MOSS2 the program follows a similar course to MOSS1 up to and including the processing carried out by module BITCODE which

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[1] See Fig. 1 in the MOSS1 Report. In particular note the ordering of module reference numbers.

assembles the 588-word bit-string representing a particular synoptic situation. However BITCODE has been modified so that

a. A User-specified set of range levels can be used--see Section 3.4;

b. Only those component fields associated with non-zero elements of the WT matrix (see Section 3.5) are bit-coded--there is no point in bit-coding a field for which no MOSS2 score is required. (Words in the 588-word bit-string associated with zero elements of WT remain as initialized--all bits set zero.)

In MOSS1 the next program-module which follows BITCODE is MATCH. In MOSS2 MATCH is replaced by program-module AREAL.

Module AREAL dimensions and initializes ten 12x12 arrays.[1] Nine of these arrays are associated with the nine component range-of-scale fields, one array per component. (The purpose of the tenth array is explained in the following Section.) Conceptually, each 12x12 array may be considered as covering the same area, geographically, as the 144 modules shown in Fig. 1 of the MOSS1 Report with a one-to-one geographical correspondence between matrix elements and modules.

Now consider that the 588-word bit-string for $F_{\tau+n}$ is to be matched against the 588-word bit-string for the verifying analysis, $A_{\tau+n}$. Associated with this match there is the nine-element matrix WT with zeroes entered in the elements corresponding to component-fields for which MOSS2 scores are not required.

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[1] Actually one 10x144 array is used but, for the purposes of description, it is more convenient to consider this as ten 12x12 arrays.

Within each bit-string the words for the SD range-of-scale are ordered as shown by sequential module reference numbers shown in Fig. 1 of the MOSS1 Report. A similar ordering exists for SL and SV modules although, of course, there are 36 SL modules and 16 SV modules.[1] Program-module AREAL therefore makes a pass through the two 588-word bit-strings, reordering the words to conform to the normal indexing of two-dimensional arrays. On completing this pass the words will have been put into a "geographical" ordering. This is shown in Fig. 1 where the array elements, from 1 through 144, correspond to the re-ordered SD modules (or words). The figure also shows the 36 SL and 16 SV modules. The shaded areas in the center of the figure show the relative sizes of the three modules which are in the ratio 1:4:9. For example SV module 1 covers the same geographical area as SD modules 1, 2, 3, 13, 14, 15, 25,26 and 27; SL module 1 covers modules 1, 2, 13 and 14.

Module AREAL now consults WT, locating the first element of WT which is non-zero. This element is associated with a particular component field and a particular 12x12 array. Assume for the moment that all elements in WT have been set greater than zero by the User.

The first element of WT is associated with the SV_{500} field. Module AREAL now accesses module BCPM (Bit Count Per Module). For array element 1 (see Fig. 1) BCPM selects the appropriate pair of words from the two bit strings, counts the matching bits, and inserts this number into element 1. This procedure is repeated for array elements 2 through 144. Note that although 144 counts are made, the net effect is that common bit-counts are entered into the nine array elements associated with a particular SV module.

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[1]This ordering is a consequence of the evolution of the MOSS system from the MII-developed Rapid Analogue Selection System (RASS). See Reference [3], MOSS1 Report.

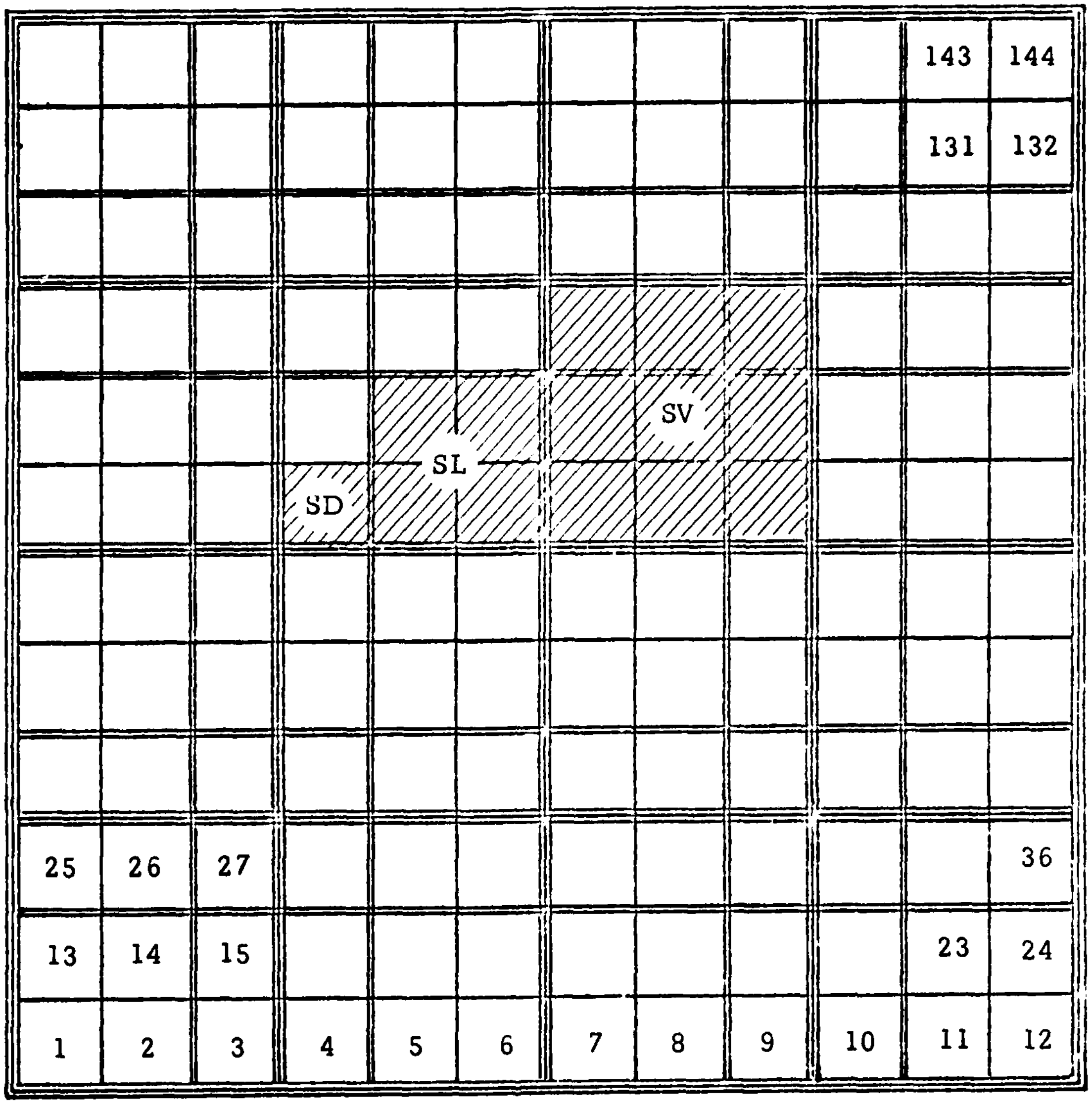

Figure 1 Geographical distribution of the 16 SV modules, the 36 SL modules and the 144 SD modules. Elements of the 12x12 matrix used to contain MOSS2 scores are numbered 1 through 144. A score for an SV module is entered in the appropriate 9 matrix elements, and for an SL module in the appropriate 4 matrix elements; there is a one-to-one correspondence between SD modules and the matrix elements.

On completing the 144 bit-counts for the pair of SV_{500} fields, a pass is made through the array to compute the quantity BCPH where

$$BCPH\left(SV_{500}\right) = \frac{1}{144} \sum_{m=1}^{144} B_m\left(SV_{500}\right)$$

where $B_m\left(SV_{500}\right)$ is the bit-count in array element m. Clearly $BCPH\left(SV_{500}\right)$--Bit Count Per Hemisphere, SV_{500}--is equivalent to the MOSS1 bit-count score for the SV_{500} component.

The procedure is repeated for the SV_{1000} and then the SV_{5-10} pairs of component fields. At this point the three arrays associated with the SV range-of-scale will be full (of modular bit-counts) and three values of BCPH will be available.

The process continues, now matching words associated with the SL range-of-scale. Again 144 counts are made for each of the three components (SL_{500}, SL_{1000}, SL_{5-10}), the net effect being that common bit-counts are entered into the four array elements associated with a particular SL module--see Fig. 1. As each array is filled the corresponding BCPH is computed and saved.

The SD components are then matched, filling the remaining three arrays and providing the final three values of BCPH.

When the overall bit-matching and counting process has been completed, including computing the nine values of BCPH, a pass is made through the first array (containing the SV_{500} bit-counts), multiplying every element of each array by 1000/60; this rescales the bit-counts to parts per thousand. As the content of each array element is rescaled it is, in addition, multiplied by the User-specified value of WT for SV_{500} (i.e., WT(1)) and the result accumulated in the corresponding element of the tenth array.

Thus, when processing of the SV_{500} array is complete, array element m contains the quantity B_m * 1000/60 while the corresponding element of the tenth array contains the quantity B_m * WT(1) * 1000/60. $BCPH\left(SV_{500}\right)$ also is rescaled to parts per 1000 at this point and, in addition, this rescaled value is multiplied by WT(1) and saved.

The above procedure is repeated for the remaining eight arrays--rescaling them to parts per thousand, accumulating the results (multiplied by the appropriate value of WT) in the corresponding elements of the tenth array, and computing values for BCPH * 1000/60 and BCPH * WT * 1000/60. The tenth array also is processed at this point in the program; see following Section.

(The processing described above assumed that all elements of WT had been set greater than zero by the User. If any elements of WT are set to zero then <u>all</u> processing (including output--see Section 3.8) is automatically by-passed for the associated pairs of component fields.)

Following bit-coding, matching and rescaling for all field components with associated non-zero values of WT, the corresponding nine 12x12 arrays contain an areal distribution of match coefficients expressed in parts per thousand.[1] This capability satisfies the requirements of Objective d. An areal distribution can be produced for any required component(s). In addition a mean hemispheric score[1] (corresponding to the MOSS1 score) is provided for each areal distribution. Examples of areal distributions of match coefficients generated by the MOSS2 capability are given in Section 3.8.

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[1] Note that these match coefficients have not been multiplied by the associated element of WT. In producing the scores WT is used only to determine whether a particular field component, n, is required (WT(n) > 0) or not (WT(n) = 0).

3.7 Weighted Combination of Range-of-Scale Match Coefficients (Objective e.)

As described in the previous Section, when the nine 12x12 arrays (for which WT $\neq$ 0) individually associated with a particular range-of-scale component have been filled with modular bit-counts, the bit-counts in element m (m = 1 $\rightarrow$ 144) are converted to parts per thousand and multiplied by the User-specified weighting factors, WT. The weighted sum is accumulated in the m^{th} element of the tenth array dimensioned in program-module AREAL. When the weighted scores for all required range-of-scale components have been accumulated a pass is made through the tenth array dividing by the sum of the contributing weight factors. The resultant array provides an areal distribution of match coefficients which is a User-weighted combination of any specified subset of the parameters in SV, SL and SD ranges-of-scale. This capability satisfies the requirements of Objective e. In addition a weighted score for the hemisphere is computed from the individual hemispheric scores.

The elements of WT contain the relative weighting factors for each contributing component. Although any numbers between .0001 and 99999 may be used for specifying the elements of WT it is recommended that the User choose these numbers such that their sum is either 1.0 or 100. For example, for a weighted combination of the SV_{500}, SL_{500} and SD_{500} components, the significance of the weighting factors is more readily appreciated if WT is given by

WT = 30, 0, 0, 50, 0, 0, 20, 0, 0

rather than by

WT = .6072, 0, 0, 1.012, 0, 0, .4048, 0, 0 .

Both specifications for WT will generate the same areal distributions of match coefficients and the same User-weighted combination of match coefficients.

3.8 Output Format and Examples

3.8.1 Output Format (Objective f.)

The various areal distributions of MOSS2 scores are held in (up to) ten 12x12 matrices, one for each of the nine component fields and one for the weighted combination of the component fields. A tabular output format has been designed to conform to a hemispheric map, polar stereographic projection, which is 7 3/4" x 7 3/4". An example of such a map for the Northern Hemisphere is shown in Fig. 2. The heavily-outlined box on the map shows the area encompassed by the 12x12 arrays.[1] This map may be used to produce a transparent overlay for use with tabulated MOSS2 scores for the Northern Hemisphere;[2] examples of the output generated by MOSS2 are given in Section 3.8.2.

3.8.2 Output Generated by MOSS2

As stated on page 26 of the MOSS1 Report, data used to develop and test MOSS1 consisted of three scenarios--72-hour sequences of 1000-mb and 500-mb forecast fields, and verifying analyses at 12-hourly intervals, emanating from analyzed fields at 00Z 12NOV78, 00Z 13NOV78 and 00Z 14NOV78. The analyzed fields were produced by the FNOC[3]

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[1] See also Fig. 1 in the MOSS1 Report.

[2] A similar map for the Southern Hemisphere is not immediately available.

[3] At that time FNWC--Fleet Numerical Weather Central.

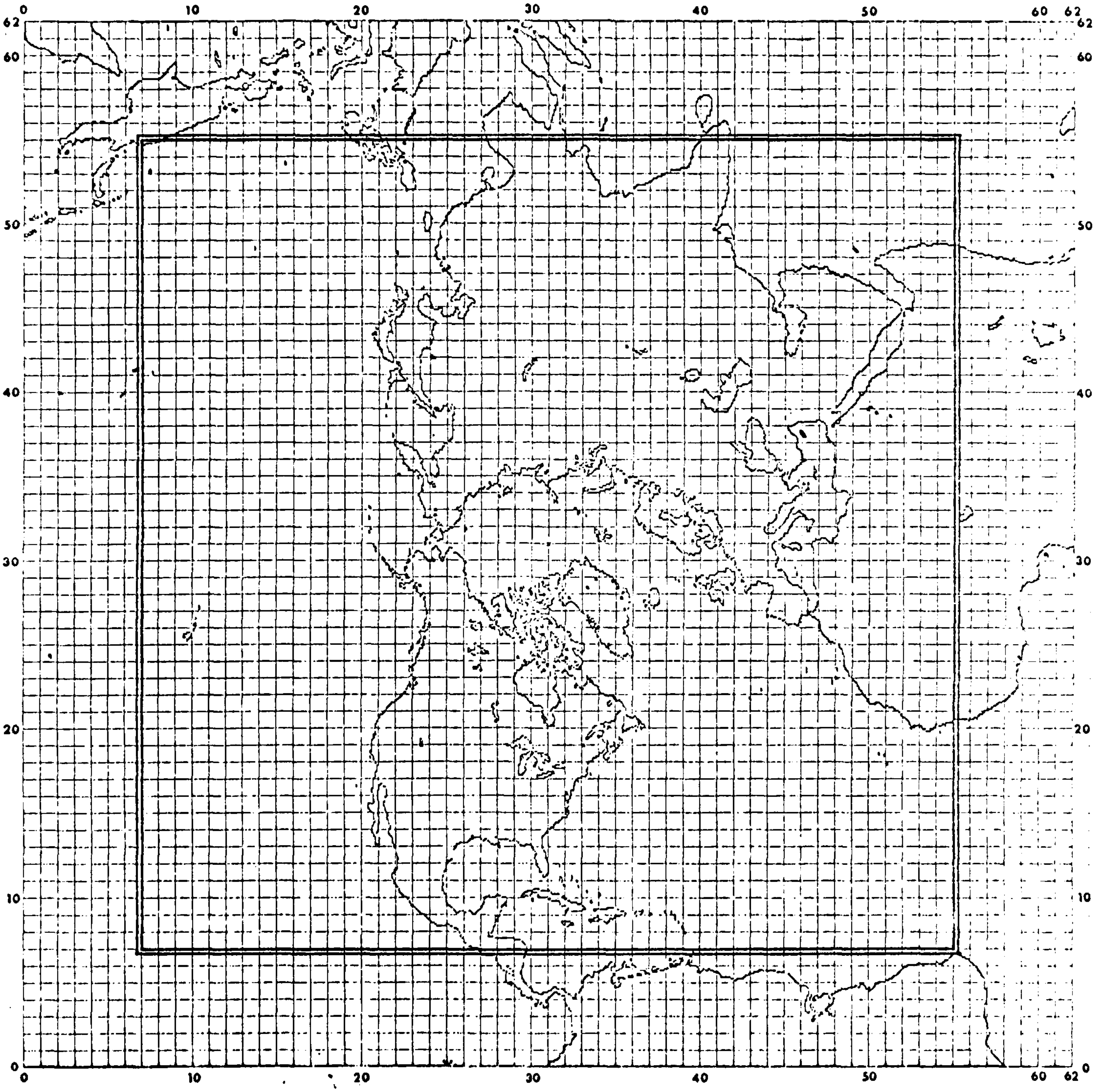

Figure 2 A polar-stereographic map of the Northern Hemisphere scaled to conform to the tabulated scores generated by MOSS2. The heavily-outlined square shows the area covered by the 144 (12x12) modules for which MOSS2 scores are produced. This figure may be used to produce a transparent overlay.

analysis system and the forecast fields by the FNOC PE model. All fields were on a 63x63 grid, north polar stereographic projection, and were produced during routine FNOC operations. The same set of test data has been used during the development of MOSS2, thus enabling many features of the MOSS2 capability to be verified for correct functioning by direct comparison with the MOSS1 output.

Table 3 shows MOSS1 scores for scenario 2 at 12-hourly intervals out to 48 hours. This table has been extracted from Table 3 of the MOSS1 Report and is reproduced here to facilitate comparison with the similar output generated by MOSS2 shown in Table 4. As can be seen, apart from the SV range-of-scale component fields, the MOSS1 and MOSS2 systems produce identical results. The relatively minor differences in hemispheric SV scores are due to the utilization, by MOSS2, of a formulation for $\overline{SV}$ rather than the stored values accessed by MOSS1--see Section 3.3.

Tables 5 through 13 show the areal distribution of match coefficients generated by MOSS2 when matching the 48-hour FNOC PE forecast emanating from the 00Z 13NOV78 analysis with the verifying analysis for 00Z 15NOV78. Tables 5 through 7 are for SV_{500}, SV_{1000} and SV_{5-10} respectively; Tables 8 through 10 are for SL_{500}, SL_{1000} and SL_{5-10}; and Tables 11 through 13 are for SD_{500}, SD_{1000} and SD_{5-10} respectively. These modular match coefficients correspond to the hemispheric MODEL scores in Table 4 under "+4". Note that hemispheric scores are automatically printed out beneath each areal distribution of MOSS2 scores.

Table 14 shows the weighted combination of the component fields--in this case all nine. The weighted hemispheric score is provided (861) together with a listing of the User-specified weights assigned to each component. During this particular run of MOSS2 a weight of 0.5 was applied to each field component. (As discussed in Section 3.7 it is recommended that, in normal use, the sum of the weights is 1.0 or 100.0).

Table 3
MOSS1 scores for scenario 2--00Z 13NOV78.

PERSISTENCE SCORES

		+0	+1	+2	+3	+4
SV	500:	1000	950	949	917	906
	1000:	1000	959	948	935	939
	5-10:	1000	954	959	923	925
SL	500:	1000	937	897	870	857
	1000:	1000	901	858	821	795
	5-10:	1000	931	901	872	855
SD	500:	1000	836	796	759	754
	1000:	1000	834	777	748	750
	5-10:	1000	815	764	742	747

MODEL SCORES

		+0	+1	+2	+3	+4
SV	500:	1000	957	936	923	911
	1000:	1000	959	949	936	920
	5-10:	1000	968	944	933	915
SL	500:	1000	962	936	920	901
	1000:	1000	934	889	852	827
	5-10:	1000	945	931	908	898
SD	500:	1000	864	844	819	806
	1000:	1000	842	814	796	778
	5-10:	1000	857	823	794	778

Table 4
MOSS2 hemispheric scores for scenario 2--00Z 13NOV78.

PERSISTENCE SCORES

00 00Z 13 NOV 78 ANALYSIS(0) : ANALYSIS(N). N=0---4

		+0	+1	+2	+3	+4	+
SV	500:	1000	954	949	920	911	
	1000:	1000	974	963	947	943	
	5-10:	1000	959	960	933	934	
SL	500:	1000	937	897	870	857	
	1000:	1000	901	859	821	795	
	5-10:	1000	931	901	872	955	
SC	500:	1000	836	796	759	754	
	1000:	1000	834	777	748	750	
	5-10:	1000	815	764	742	747	

MODEL SCORES

00 00Z 13 NOV 78 ANALYSIS(N) : FORECAST(N). N=0---4

		+0	+1	+2	+3	+4	+
SV	500:	1000	955	938	925	910	
	1000:	1000	971	968	952	939	
	5-10:	1000	963	945	929	923	
SL	500:	1000	962	936	920	901	
	1000:	1000	934	889	852	827	
	5-10:	1000	945	931	919	898	
SC	500:	1000	864	844	819	806	
	1000:	1000	842	814	796	778	
	5-10:	1000	857	823	794	778	

Table 5

MOSS2 scores--$F_{\tau+48}(SV_{500}):A_{\tau+48}(SV_{500})$, τ = 00Z 13NOV78.

PARTS/THOUSAND, SV 500 78111300AE: 78111300BE

933	933	933	883	883	883	900	900	900	900	900	900
933	933	933	883	883	883	900	900	900	900	900	900
933	933	933	883	883	883	900	900	900	900	900	900
850	850	850	833	833	833	833	833	833	883	883	883
850	850	850	833	833	833	833	833	833	883	883	883
850	850	850	833	833	833	833	833	833	883	883	883
883	883	883	950	950	950	983	983	983	950	950	950
883	883	883	950	950	950	983	983	983	950	950	950
883	883	883	950	950	950	983	983	983	950	950	950
950	950	950	967	967	967	967	967	967	900	900	900
950	950	950	967	967	967	967	967	967	900	900	900
950	950	950	967	967	967	967	967	967	900	900	900

HEMISPHERIC SCORE: 910

Table 6

MOSS2 scores--$F_{\tau+48}(SV_{1000}) : A_{\tau+48}(SV_{1000})$, τ = 00Z 13NOV78.

PARTS/THOUSAND, SV 1000 78111300AE: 78111300BE

917	917	917	933	933	933	950	950	950	917	917	917
917	917	917	933	933	933	950	950	950	917	917	917
917	917	917	933	933	933	950	950	950	917	917	917
933	933	933	850	850	850	900	900	900	950	950	950
933	933	933	850	850	850	900	900	900	950	950	950
933	933	933	850	850	850	900	900	900	950	950	950
967	967	967	917	917	917	900	900	900	917	917	917
967	967	967	917	917	917	900	900	900	917	917	917
967	967	967	917	917	917	900	900	900	917	917	917
1000	1000	1000	950	950	950	950	950	950	933	933	933
1000	1000	1000	950	950	950	950	950	950	933	933	933
1000	1000	1000	950	950	950	950	950	950	933	933	933

HEMISPHERIC SCORE: 930

Table 7

MOSS2 scores--$F_{\tau+48}(SV_{5-10}):A_{\tau+48}(SV_{5-10})$, τ = 00Z 13NOV78.

PARTS/THOUSAND, SV 5-10 78111300AE: 78111300BE

933	933	933	933	933	933	900	900	900	950	950	950
933	933	933	933	933	933	900	900	900	950	950	950
933	933	933	933	933	933	900	900	900	950	950	950
867	867	867	917	917	917	917	917	917	917	917	917
867	867	867	917	917	917	917	917	917	917	917	917
867	867	867	917	917	917	917	917	917	917	917	917
950	950	950	933	933	933	833	833	833	933	933	933
950	950	950	933	933	933	833	833	833	933	933	933
950	950	950	933	933	933	833	833	833	933	933	933
983	983	983	900	900	900	983	983	983	917	917	917
983	983	983	900	900	900	983	983	983	917	917	917
983	983	983	900	900	900	983	983	983	917	917	917

HEMISPHERIC SCORE: 923

Table 8

MOSS2 scores--$F_{\tau+48}(SL_{500}):A_{\tau+48}(SL_{500})$, τ = 00Z 13NOV78.

PARTS/THOUSAND, SL 500 78111300AE: 78111300BE

983.	983.	950.	950.	983.	983.	900.	900.	967.	967.	967.	967.
983.	983.	950.	950.	983.	983.	900.	900.	967.	967.	967.	967.
917.	917.	883.	883.	833.	833.	783.	783.	817.	817.	917.	917.
917.	917.	883.	883.	833.	833.	783.	783.	817.	817.	917.	917.
933.	933.	867.	867.	850.	850.	867.	867.	883.	883.	917.	917.
933.	933.	867.	867.	850.	850.	867.	867.	883.	883.	917.	917.
883.	883.	833.	833.	933.	933.	850.	850.	983.	983.	983.	983.
883.	883.	833.	833.	933.	933.	850.	850.	983.	983.	983.	983.
900.	900.	883.	883.	833.	833.	883.	883.	917.	917.	900.	900.
900.	900.	883.	883.	833.	833.	883.	883.	917.	917.	900.	900.
900.	900.	917.	917.	900.	900.	917.	917.	917.	917.	900.	900.
900.	900.	917.	917.	900.	900.	917.	917.	917.	917.	900.	900.

HEMISPHERIC SCORE: 901

Table 9

MOSS2 scores--$F_{\tau+48}(SL_{1000}):A_{\tau+48}(SL_{1000})$, τ = 00Z 13NOV78.

PARTS/THOUSAND, SL 1000 78111300AE: 78111300BE

883	883	817	817	850	850	817	817	867	867	883	883
883	883	817	817	850	850	817	817	867	867	883	883
800	800	700	700	783	783	650	650	567	567	733	733
800	800	700	700	783	783	650	650	567	567	733	733
767	767	817	817	800	800	900	900	817	817	800	800
767	767	817	817	800	800	900	900	817	817	800	800
883	883	817	817	783	783	917	917	833	833	933	933
883	883	817	817	783	783	917	917	833	833	933	933
933	933	767	767	783	783	817	817	883	883	917	917
933	933	767	767	783	783	817	817	883	883	917	917
900	900	867	867	867	867	767	767	983	983	883	883
900	900	867	867	867	867	767	767	983	983	883	883

HEMISPHERIC SCORE: 827

Table 10

MOSS2 scores--$F_{\tau+48}(SL_{5-10}):A_{\tau+48}(SL_{5-10})$, τ = 00Z 13NOV78.

PARTS/THOUSAND, SL 5-10 78111300AE: 78111300BE

933.	933.	950.	950.	900.	900.	850.	850.	950.	950.	983.	983.
933.	933.	950.	950.	900.	900.	850.	850.	950.	950.	983.	983.
933.	933.	983.	983.	900.	900.	767.	767.	800.	800.	867.	867.
933.	933.	983.	983.	900.	900.	767.	767.	800.	800.	867.	867.
833.	833.	850.	850.	833.	833.	850.	850.	900.	900.	950.	950.
833.	833.	850.	850.	833.	833.	850.	850.	900.	900.	950.	950.
867.	867.	883.	883.	833.	833.	900.	900.	867.	867.	917.	917.
867.	867.	883.	883.	833.	833.	900.	900.	867.	867.	917.	917.
950.	950.	850.	850.	783.	783.	867.	867.	900.	900.	933.	933.
950.	950.	850.	850.	783.	783.	867.	867.	900.	900.	933.	933.
933.	933.	950.	950.	950.	950.	1000.	1000.	950.	950.	967.	967.
933.	933.	950.	950.	950.	950.	1000.	1000.	950.	950.	967.	967.

HEMISPHERIC SCORE: 898

Table 11

MOSS2 scores--$F_{\tau+48}(SD_{500}):A_{\tau+48}(SD_{500})$, τ = 00Z 13NOV78.

PARTS/THOUSAND, SD 500 78111300AE: 78111300BE

833	850	950	883	850	767	783	867	900	867	883	850
883	917	950	967	900	783	583	650	817	950	883	883
917	933	933	633	650	700	767	783	867	800	817	983
917	933	817	783	633	783	767	600	700	733	883	1000
933	750	533	717	700	783	733	683	650	700	817	950
933	733	667	633	717	767	700	483	700	717	967	917
933	750	767	500	617	667	567	717	833	833	850	917
883	750	617	600	717	800	750	733	783	800	900	950
933	867	733	567	867	633	733	850	750	850	900	867
867	783	850	583	717	817	867	700	700	933	867	900
867	883	917	817	917	900	833	767	817	950	850	950
867	783	900	950	933	967	900	917	867	850	833	933

HEMISPHERIC SCORE: 806

Table 12

MOSS2 scores--$F_{\tau+48}(SD_{1000}):A_{\tau+48}(SD_{1000})$, τ = 00Z 13NOV78.

PARTS/THOUSAND, SD 1000 78111300AE: 78111300BE

783.	833.	767.	833.	883.	850.	850.	683.	850.	867.	933.	933.
883.	900.	917.	883.	817.	683.	650.	683.	833.	867.	883.	867.
883.	917.	883.	733.	667.	650.	633.	667.	750.	733.	883.	800.
900.	850.	700.	667.	583.	717.	650.	600.	583.	617.	783.	800.
933.	750.	600.	767.	700.	800.	733.	600.	650.	683.	900.	917.
867.	717.	800.	617.	733.	717.	633.	700.	683.	667.	667.	833.
767.	567.	800.	483.	683.	633.	833.	633.	633.	700.	817.	883.
800.	733.	600.	583.	783.	717.	783.	600.	550.	750.	950.	850.
867.	900.	650.	650.	583.	783.	833.	750.	733.	817.	800.	967.
833.	917.	883.	783.	667.	817.	767.	733.	700.	833.	900.	933.
867.	850.	883.	783.	800.	850.	833.	733.	700.	917.	933.	933.
850.	833.	967.	867.	900.	850.	800.	867.	867.	850.	917.	933.

HEMISPHERIC SCORE: 778

Table 13

MOSS2 scores--$F_{\tau+48}(SD_{5-10}):A_{\tau+48}(SD_{5-10})$, τ = 00Z 13NOV78.

PARTS/THOUSAND, SD 5-10 78111300AE: 78111300BE

800	867	817	883	850	717	733	867	900	783	883	933
817	933	850	833	817	800	683	767	850	917	917	833
833	867	867	700	517	650	700	700	717	800	800	850
833	817	650	650	450	750	700	650	733	817	750	817
883	833	600	683	633	750	700	667	683	717	817	883
867	583	633	483	550	767	717	583	650	800	783	850
783	700	717	550	400	633	733	633	567	717	817	833
783	783	733	733	717	717	733	817	783	767	867	850
767	800	750	500	700	650	550	750	817	967	850	950
883	867	900	533	667	750	883	817	850	917	900	917
883	833	950	867	850	867	900	850	867	867	900	900
817	817	917	950	950	900	850	800	800	783	867	933

HEMISPHERIC SCORE: 778

Table 14

Combined MOSS2 scores--$F_{\tau+48} : A_{\tau+48}$, τ = 00Z 13NOV78.
(Assigned component weights are listed at the foot of the table.)

WEIGHTED COMBINATION, PARTS/THOUSAND   78111300AE: 78111300BE

889	904	893	896	896	869	854	859	909	896	922	924
907	926	913	906	891	861	804	874	893	920	920	909
896	906	893	820	789	807	783	789	807	809	865	880
883	878	820	907	754	819	774	744	761	789	954	876
881	835	769	811	791	824	826	802	804	828	883	907
872	802	809	763	787	815	813	761	809	837	859	891
880	828	846	763	783	809	835	819	826	859	902	919
878	856	809	806	841	843	850	837	835	867	928	920
906	906	826	780	817	807	822	848	857	904	900	926
922	920	896	802	807	844	887	857	872	904	907	917
920	915	935	891	900	906	906	881	904	926	909	920
911	900	939	924	924	917	904	907	920	898	902	922

HEMISPHERIC SCORE: 861

COMPONENT WEIGHTS:

SV 500	=	.50
SV 1000	=	.50
SV 5-10	=	.50
SL 500	=	.50
SL 1000	=	.50
SL 5-10	=	.50
SO 500	=	.50
SO 1000	=	.50
SO 5-10	=	.50
TOTAL	=	4.50

3.8.3 Discussion of Results

Tables 5 through 13 show the results of utilizing the MOSS2 system to match the nine component fields of the 48-hour FNOC PE forecast for 00Z 15NOV78 with the verifying analysis. Table 14 is a uniformly-weighted combination of Tables 5 through 13. This synoptic situation was chosen to correspond to forecast and analysis fields presented in the MOSS1 Report, thus facilitating study of the areal distribution of MOSS2 match coefficients.

Referring to the MOSS1 Report, Figs. 3 through 14 show the 1000-mb and 500-mb analyzed scenarios from 00Z 12NOV78 through 00Z 17NOV78. Figures 5 and 6 show the baseday situations at 1000 mb and 500 mb for 00Z 13NOV78 from which originated the 48-hour forecast for 00Z 15NOV78. The 1000-mb and 500-mb forecast fields for 00Z 15NOV78 are shown in Figs. 17 and 18. Figures 9 and 10 show the 1000-mb and 500-mb verifying analyses. Figures 21 through 32 in the MOSS1 Report show the results of separating the 1000-mb and 500-mb 00Z 15NOV78 analyses (Figs. 9 and 10 respectively), and the 1000-mb and 500-mb 48-hour forecast fields verifying at 00Z 15NOV78 (Figs. 17 and 18 respectively), into their SV, SL and SD component ranges-of-scale.

The following table shows the correspondence between Tables 5 through 14 (MOSS2) and the MOSS1 figures:

Table 15

MOSS2	MOSS1	MOSS2 Hemispheric Score
Table 5 corresponds to the match of	Fig. 24:Fig. 22	910
6	Fig. 23:Fig. 21	930
7	--	923
8	Fig. 28:Fig. 26	901
9	Fig. 27:Fig. 25	827
10	--	898
11	Fig. 32:Fig. 30	806
12	Fig. 31:Fig. 29	778
13	--	778
14	--	861

Figure 3 shows the result of hand-contouring the MOSS2 scores provided by Table 14 using Fig. 2 to provide a geographical background. Thus Fig. 3 shows "isopleths of similarity" between the 48-hour forecast for 00Z and the verifying analysis. In this instance the MOSS2 scores provide composite local measures of the degree of similarity between all nine pairs of component fields--in other words it is a three-dimensional comparison. Note that all nine pairs made equal contributions to the MOSS2 scores shown in Table 14 and Fig. 3--an optimum weighting for each component-pair has yet to be determined.

In Fig. 3 the contours show the spatial distribution of the degree of pattern similarity between the actual synoptic situation at 00Z 15NOV78 and the 48-hour forecast synoptic situation for the same time. (Note that a "synoptic situation" is defined as being represented by the 500-mb and 1000-mb height fields and the 500-1000-mb thickness field; and the degree of pattern similarity is determined by the pattern-specifying parameters and the bit-coding and matching techniques encompassed by the MOSS system.) *Subjective evaluation of the* MOSS2 scores by a mental comparison between two total synoptic situations is very difficult--as will be shown, an easier task is to evaluate the results produced by matching a single pair of component fields. The point to note with regard to Fig. 3 is that there are clearly discernible features in the MOSS2 scores; the scores are not random. These features extend over a number of modules and are associated with the local degree of match (or mismatch) between the forecast synoptic situation and the verifying analysis. In general terms it can be seen that the forecast verifies relatively well in low latitudes but is less successful in middle latitudes (apart from, in this particular case, in the vicinity of the Davis Strait).

For ease of reference Fig. 4 reproduces Fig. 30 of the MOSS1 Report and shows the SD_{500} analysis for 00Z 15NOV78. Figure 5 (corresponding to Fig. 32, MOSS1) shows the 48-hour FNOC PE forecast

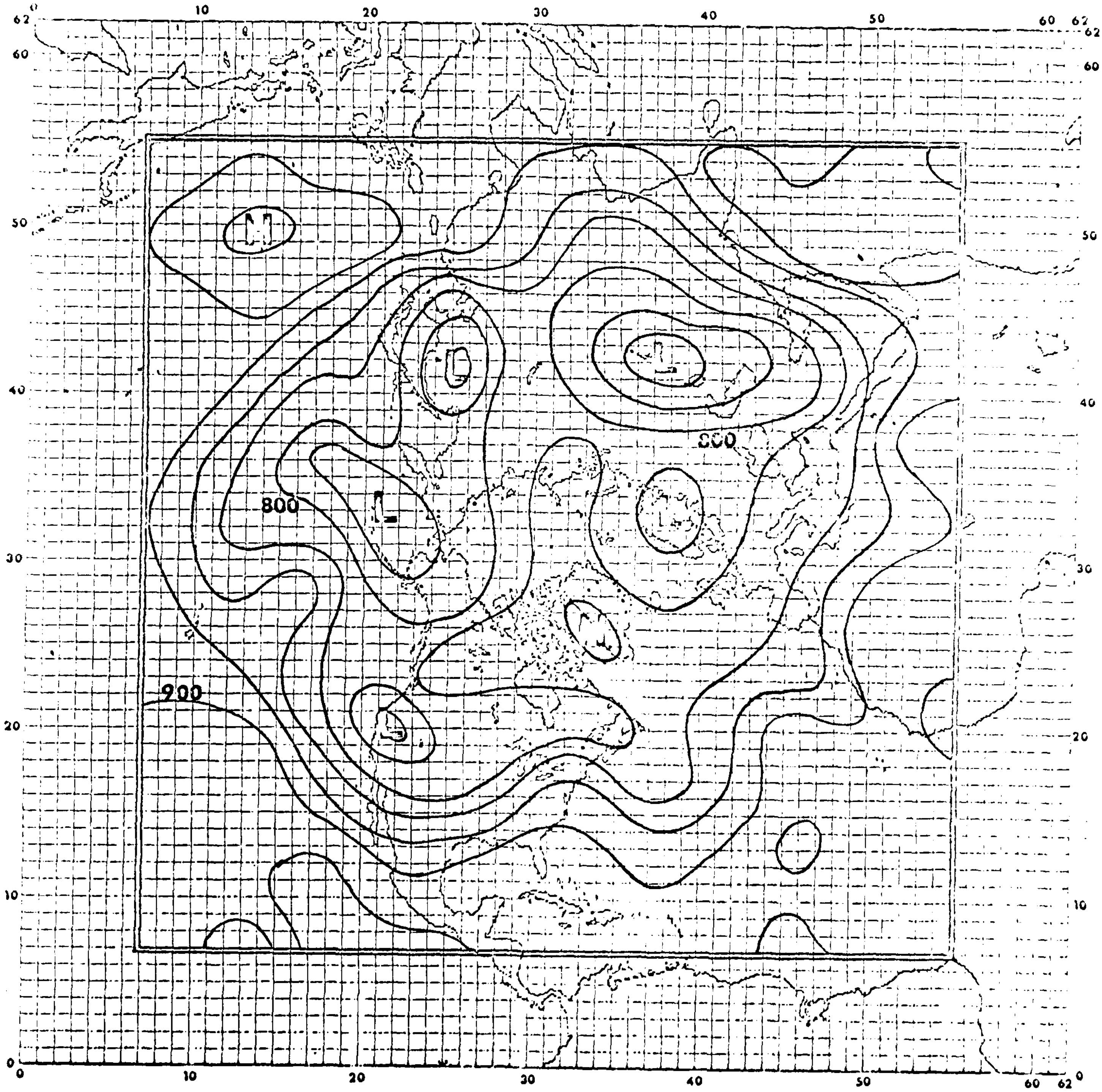

Figure 3 Isopleths of pattern similarity, based on equally-weighted contributions from all nine pairs of component fields, between a forecast synoptic situation and the verifying analysis. Contour interval is 25 "units".

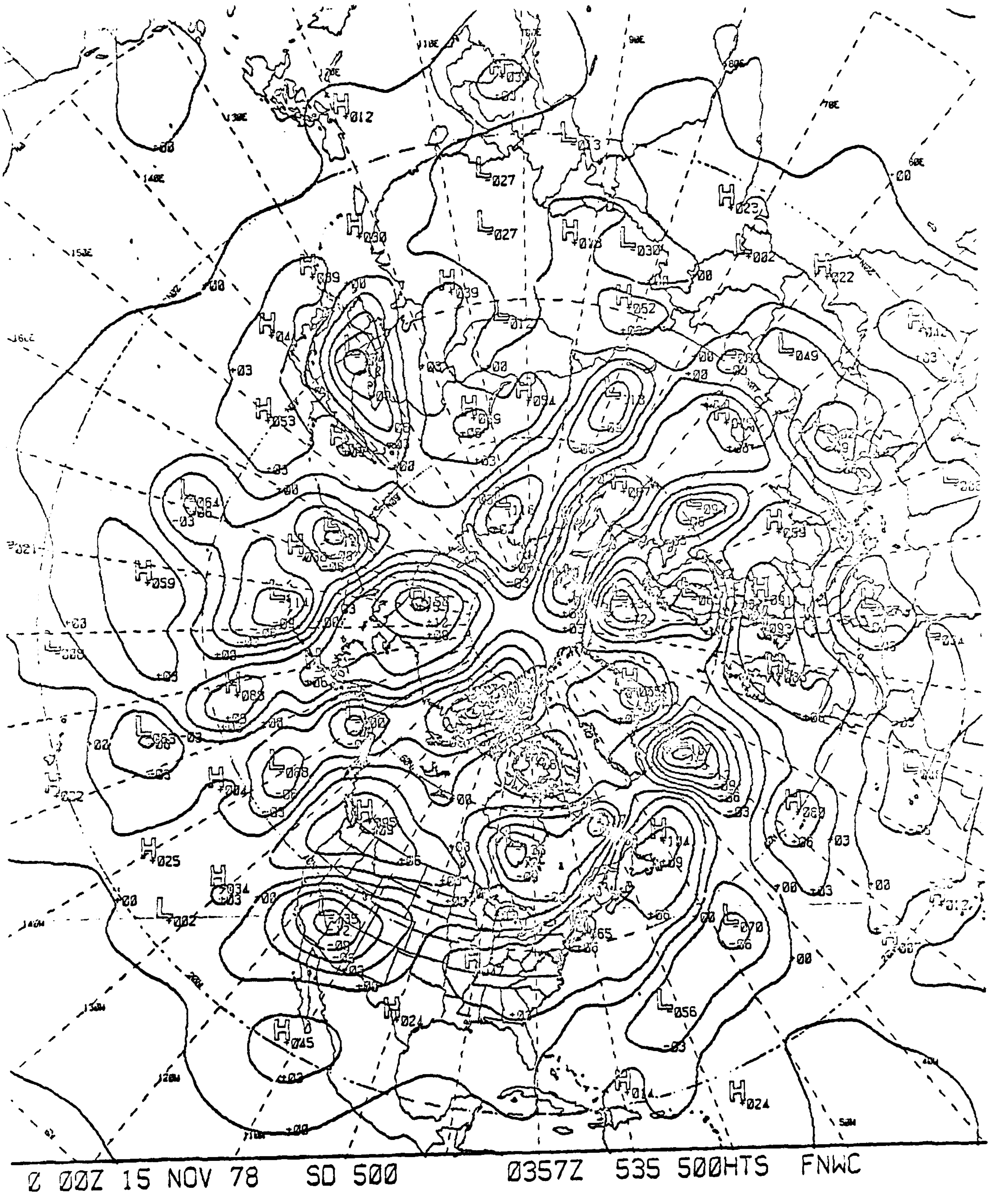

Figure 4

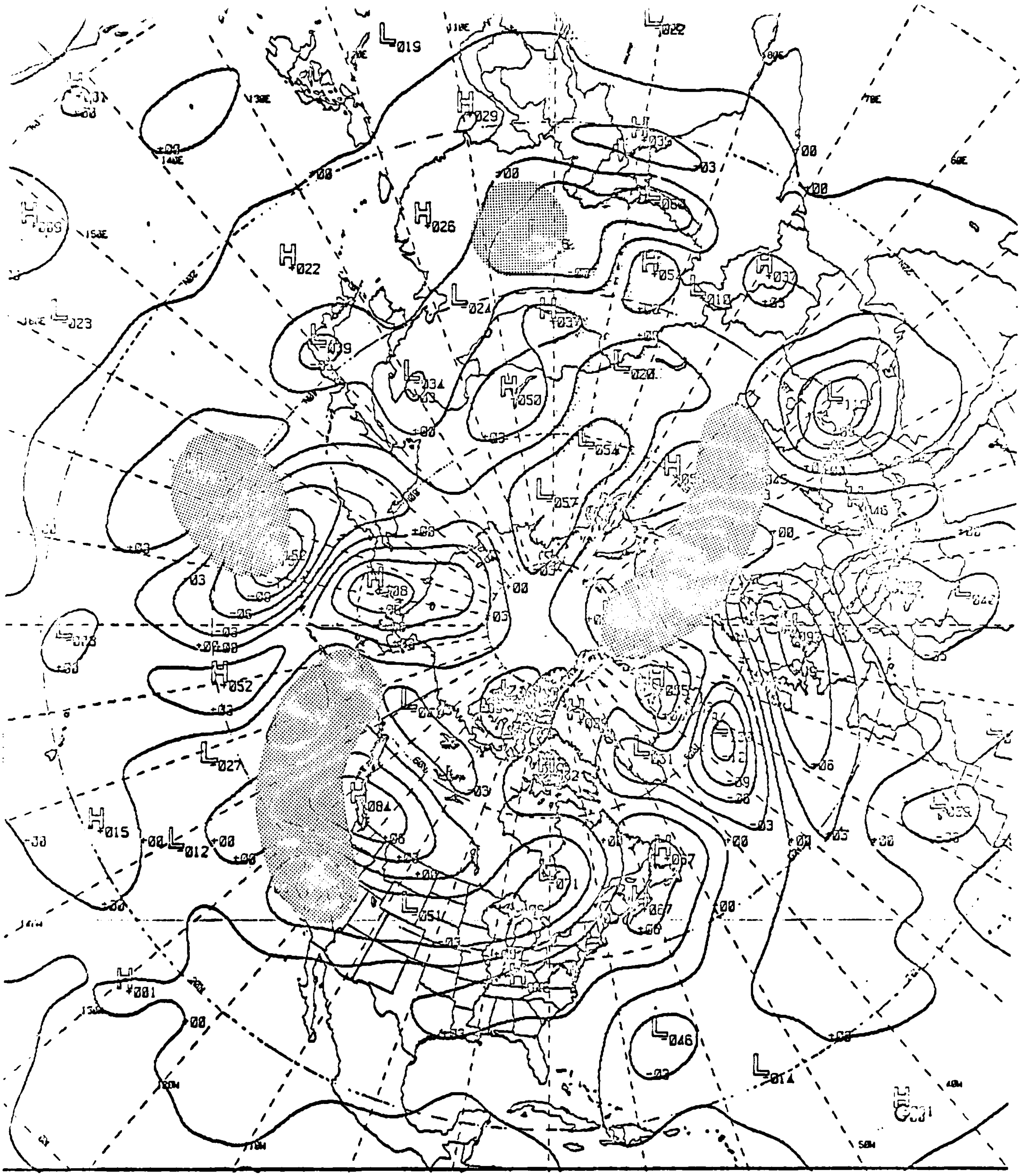

Figure 5

verifying at the same time. (The significance of the added shading is discussed below.) One point is immediately apparent--the forecast field is markedly smoother than the verifying analysis; variance has been lost.[1]

The areal distribution of MOSS2 scores provided by matching these two figures is given in Table 11. Figure 6 shows the "isopleths of similarity" produced by hand-contouring Table 11 using Fig. 2 to provide a geographical background. The four regions for which MOSS2 scores are about 600 or less are shown (approximately) by the four shaded areas on Fig. 5. If now Figs. 4 and 5 are compared the shaded areas show regions in which the forecast was less successful (where the measure of the "degree of success" is based on MOSS2 scores).

In studying the differences between two fields in association with MOSS2 scores, it must be remembered that it is the local degree of pattern similarity which is determined by MOSS2; the score takes into account not only corresponding differences in absolute field-values but also differences in the magnitude and orientation of gradients.

As an example of the significance and value of MOSS2 scores in providing an objective measure of the degree of success of a forecast, consider the SD_{500} verifying analysis (Fig. 4) and the associated 48-hour forecast (Fig. 5) for the shaded region (shown in Fig. 5) over the West Coast of the USA and the Eastern Pacific. In this region it is felt that many analysts would consider the forecast to verify particularly well and would have little hesitation, for the shaded area, in selecting Fig. 5 as a good analogue for Fig. 4 (or vice versa). However the MOSS2 scores indicate

[1] A technique for estimating the Variance Loss Factor is outlined in the MOSS1 Report on page 75. This capability may be added to MOSS as a further development.

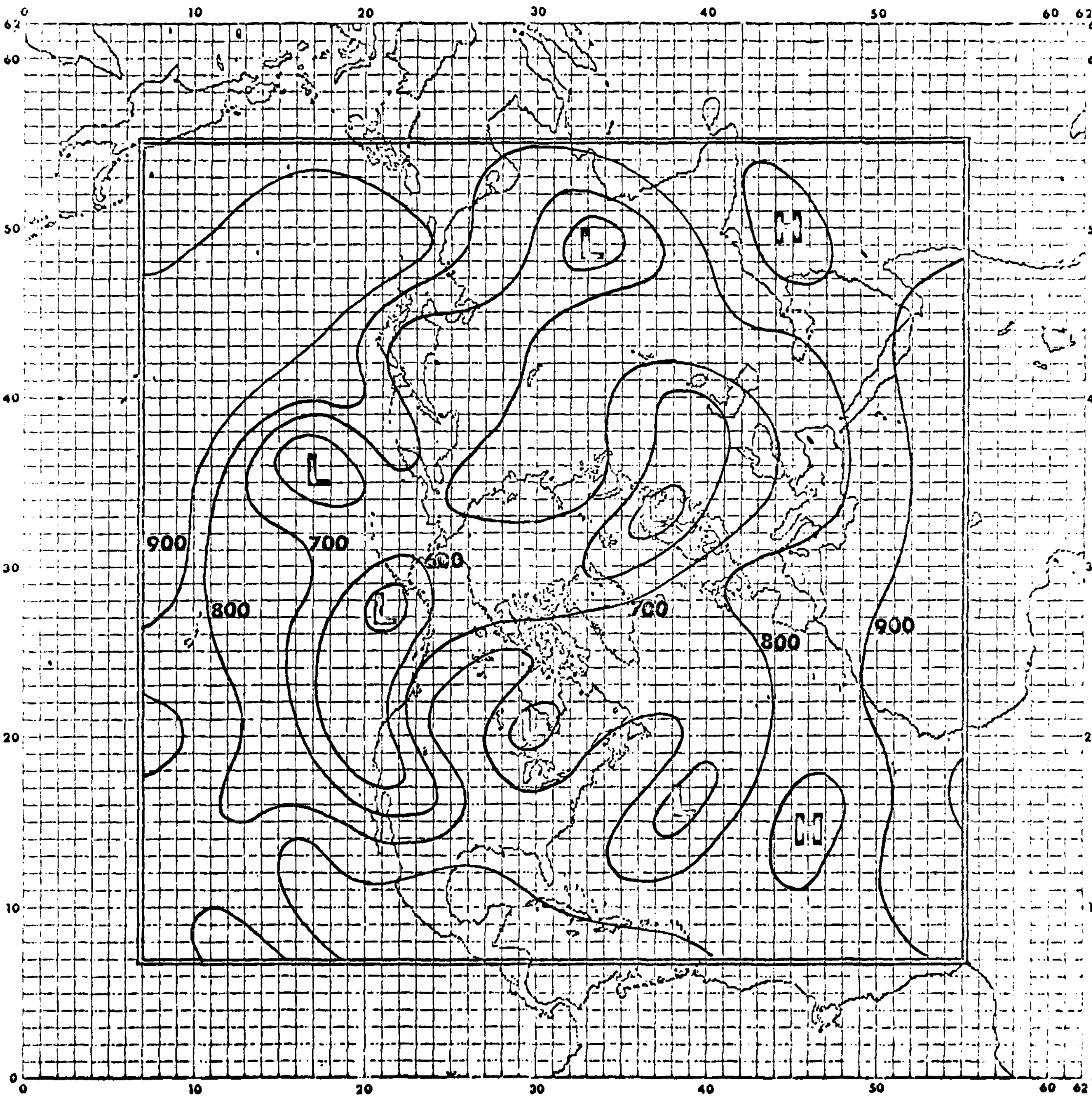

Figure 6 Isopleths of pattern similarity, based on MOSS2 scores, between a 48-hour forecast for the SD_{500} field (see Fig. 5) and the verifying analysis (see Fig. 4). Contour interval is 100 "units".

that the two patterns match particularly poorly in this region. Figure 7 shows the two SD_{500} fields superposed:

Figure 7 The SD_{500} forecast (shown by dashes) and verifying analysis (solid lines) for a region of low MOSS2 scores. This region is outlined by the dots.

The reason for the low MOSS2 scores is now readily apparent--based on absolute values and gradients (magnitude and orientation), the two patterns in the area enclosed by the dots are highly dissimilar. In fact a forecast of the SD_{500} component of the geostrophic wind based on the SD_{500} forecast field would differ, over most of the area, by 90° or more from the same winds diagnosed from the SD_{500} analysis. The gradient magnitudes also are very different--in general the strongest analyzed gradients occur where the forecast gradients are weakest. In Section 1 it was stated that "the ability to objectively examine specific regions of hemispheric forecast fields is desirable". The above example shows that MOSS2 has this capability,[1] making "possible the consistent monitoring of regional biases in forecast accuracy".

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[1]It also demonstrates the ease with which, based on subjective assessment, a poor forecast (or analogue) may be mistaken for a good one.